Indonesian Journal of Computer Science
ISSN 2549-7286 (*online*)
Jln. Khatib Sulaiman Dalam No. 1, Padang, Indonesia
Website: ijcs.stmikindonesia.ac.id | E-mail: ijcs@stmikindonesia.ac.id

Fog Computing in Next Generation Networks: A Review

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Article Information

Submitted : 21 Mar 2024
Reviewed: 25 Mar 2024
Accepted : 8 Apr 2024

Keywords

cloud computing, edge computing, Fog computing, and Internet of Things (IoT)

Abstract

Cloud, Edge, and Fog computing has recently attracted significant attention in both industry and academia. However, finding their definition in computing paradigms and the correlation between them is difficult. In order to support modern computing systems, the cloud, edge devices, and fog computing offer high-quality services, lower latency, multi-tenancy, mobility support, and many other features. Fog/edge computing is an emerging computing paradigm that uses decentralized resources at the edge of a network to process data closer to user devices, like smartphones and tablets, as an alternative to using remote and centralized cloud data center resources. Fog networking or fogging is one of the best used models recently. By addressing this issue, this work serves as a valuable resource for those who will come after. Initially, we present an overview modern computing models and associated areas of interest research. After that, we discuss each paradigm. After that, we go into great detail about fog computing, highlighting its exceptional function as the link between edge, cloud, and IoT computing. Finally, we briefly outline open research questions and future directions in Edge, Fog, Cloud, and IoT computing.

A. Introduction

During the past ten years, there has been an important change in the paradigms surrounding computing. The most well-known and established one is definitely cloud computing, a paradigm developed as a result of the requirement to use "computing as a utility" [3], making it simple to develop new Internet services. Generally, data generated by sensors in a smart factory or city, or by user devices like smartwatches and smartphones, is sent to clouds located far away to be processed and stored [25]. Up until the Internet of Things (IoT), a widespread network of smart appliances and devices, showed every disadvantage of this highly centralized paradigm, cloud computing was a very popular research topic. The Internet of Things revolution has increased interest in decentralized paradigms by opening up new research avenues. With the goal of delivering cloud power at the network edge and addressing many of the emerging issues that cloud computing alone is unable to handle, like latency, bandwidth, and connectivity, edge computing emerged in this context [1]. Therefore, a number of Edge computing solutions have been proposed [12], Thus, "edge computing" refers to a computing paradigm that utilizes resources placed at the network's edge. [7], [8]. All cloud services present two major challenges for edge devices. These include: 1) The rapidly increasing amount of data being produced by IoT devices will lead to network congestion and performance issues at the edge of infrastructure. 2) A cloud-only solution is insufficient for many tasks because of issues with performance, security, bandwidth, dependability, and many other issues. Fog computing's main focus is performance control; efficiency and latency have helped make it successful. "Fog computing" refers to a model that uses cloud and edge resources simultaneously [9], [10]. Fog computing, the ultimate development of Edge computing principles, comes to attention in this Edge computing fashion. [5]. A distributed computing paradigm known as "fog computing" serves as a mediator between Internet of Things

(IoT) devices and sensors and cloud datacenters. In order to extend Cloud-based services closer to IoT devices/sensors, it provides computing, networking, and storage facilities [6]. Additionally, it supports the extension of cloud- based services. Thus, it aids in providing effective services, such as a large reduction in latency [11]. The existence of fog computing, however, enhances cloud services rather than completely replacing them [12]. In this paper we go into great detail about the key differences between the cloud, edge, and fog computing paradigms. Also, we offer a taxonomy of cloud, edge, and fog computing based on the essential characteristics and related difficulties. To highlight some important research directions for those interested in the field, we briefly go over some of the major challenges that are still unresolved in IoT, Cloud, Edge, and Fog computing.

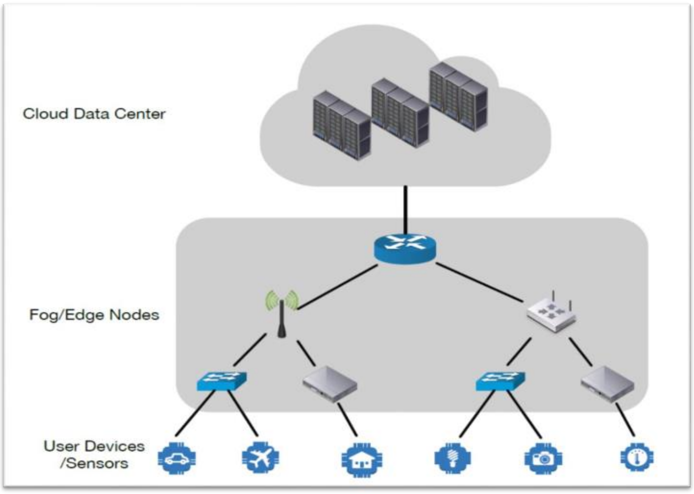

Figure 1. A fog/edge computing model comprising the cloud, resources at the edge of the network, and end-user devices or sensors

B. Literature Review

According to R.O. Aburukba (2021) The cloud computing paradigm offers users the perception of having access to limitless computational resources. Nevertheless, cloud computing does not meet the time-critical demands of applications. The primary obstacle in the cloud computing paradigm is the inherent latency between the edge IoT device and the cloud data center, as well as the latency between the cloud data center and the edge device. [17]. According to Y. Zhang, A. Taherkordi (2018) Each cloudlet is a compact data center, positioned within close proximity to mobile devices in public areas like hospitals, office buildings, and shopping malls, in order to facilitate the use of specific applications. [5]. The article of Mijuskovic,(2021) is aims to develop a methodology that explores the potential of IoT and cloud/fog-edge computing in enhancing the dependability, visibility, and error identification in operations within a smart transportation and logistics system. The strategy aims to facilitate the coordinated utilization of several logistical modalities to enhance decision-making and transparency for organizations. [20]. In the study of L. Wei, C. Xu, T. Wang (2019) In the cloud computing paradigm, sensor data is communicated to servers within networks and subsequently processed on the servers located in a cloud infrastructure. In this scenario, the networks are experiencing congestion and the servers are overwhelmed as a result of the high volume of traffic generated by the sensors. To optimize system efficiency, minimize wait time, and reduce network traffic, data and processes are dispersed over both cloud servers and fog nodes in fog computing models. [34]. According to R. Jindal (2020) Cloud computing is a significant computing paradigm that can handle all types of computations, even those that were previously considered lesser in scale. However, there are instances where its effectiveness diminishes when the objective is to accomplish a task in real-time, with extremely minimal delay. Thus, fog computing was created as an additional computing paradigm to complement cloud computing. [39]. The subject matter of A. Ahmed (2016) Edge provides application developers and content providers with up-to-date information about the Radio Access Network (RAN), including user location, network load, and network congestion. The up-to-the-minute network data enhances context-specific services for mobile users, leading to heightened user happiness and improved quality of experience (QoE). MEC enhances the responsibility of the edge network by enabling services and computational operations to be performed at the edge network level, resulting in reduced network latency and bandwidth usage for subscribers. The technology enables network operators to outsource the management of the radio network edge to a third party. This facilitates the introduction of new apps and edge services to mobile subscribers. The main objective of MEC is to provide applications and services with minimal delay and data usage. [11]. Per study of Li, R. Hou (2017) Suggest deploying a Mobile-Edge Computing (MEC) server within the Radio Access Network (RAN) to enable connection with a group of base stations located alongside roadways. This will facilitate the provision of adaptable vehicle-related services and effective radio network management. [10]. The article of M. Heydari, A. Mylonas (2019) focused on expanding the Attribute Based Access Control

(ABAC) concept. A novel predictive model was proposed. This text discusses the issue of uncertainty in the access control authentication process of fog computing. In the study of Parikh, (2019) Cloud computing has emerged as the primary platform for the storage and analysis of data. Nevertheless, the process of storing data in the cloud presents a distinct array of obstacles and problems related to security. In addition, as the amount of data created by each device continues to grow, the conventional cloud computing model has proven to be inadequate in resolving issues such as significant delays, restricted bandwidth, and limited resources. New computational paradigms such as edge and fog computing are suggested to address the problems of the previous paradigm directly at the device or in close proximity to it. [40]. In the paper of Rapuzzi, M. Repetto (2018) Emphasize the importance of developing situational awareness to detect and mitigate network threats. In this analysis, we provide a concise overview of the primary constraints of existing cyber-security models in relation to the growing fog/edge architectures. Additionally, we examine how the current obstacles and emerging trends are driving a shift from vertical security frameworks to more horizontal and distributed designs. We present a comprehensive framework that incorporates essential components and advanced technologies to establish the required understanding and vigilance regarding network dangers across extensive and diverse computing and networking environments. [42]. Per the study of Y. Winnie (2018) the Managing large volumes of data on the cloud, particularly healthcare data that necessitates real-time computation and storage, can pose significant challenges. Data security is a significant concern in cloud computing. Fog computing provides a solution for surmounting the problems. Fog nodes operate at the periphery and bolster data security, precision, and consistency while diminishing latency, a critical consideration for applications such as medical data. [29]. In the work of Karatas, (2019) presents a geographically distributed hierarchical cloud and fog computing based Internet of Things (IoT) architecture. Additionally, it introduces methods for allocating IoT data to the components, specifically cloud and fog data centers, within the proposed architecture. Data is classified into various categories, and each category of data may be required by multiple applications. [31]. Per study of Dehnavi, (2019) the punctuality and dependability are essential prerequisites for industrial applications. Therefore, it is crucial to consider these two objectives meticulously while designing a smart factory. Employing a hybrid Cloud, which integrates a public Cloud with a private Cloud, is a well-recognized approach to enhance the dependability and promptness of Cloud computing. Nevertheless, when it comes to time-critical applications, relying just on a hybrid Cloud is insufficient to ensure the timely completion of their rigorous deadlines. Implementing a middle computer layer, known as Fog, between the factory and the Cloud, offers a viable approach for addressing the reliability and latency needs of timesensitive applications with rigorous constraints. [32]. This study (Gazori,2020) specifically addresses the task scheduling of fog-based Internet of Things (IoT) applications. The objective is to minimize the overall service delay and computation cost in the long run, while considering the limitations of resources and deadlines. In order to tackle this issue, we have employed the reinforcement learning methodology and put forth a scheduling algorithm based on Double Deep Q-Learning (DDQL). This algorithm utilizes the target network and experience replay techniques. [33].

C. The Computing Paradigms Roadmap

This part contains a roadmap that guides us through the initial appearance and research trends associated with the four key subjects of this paper: edge, fog, cloud, and Internet of Things computing.

A. Methodology

The outcomes that are shown in this section were acquired using particular standards. The presence or lack of keywords in the document title was used to filter manuscripts. Interest grabbing terms included edge computing, fog computing, cloud computing, and the Internet of Things. These decisions have been chosen because, instead of offering a thorough and in-depth statistical study of the literature, our goal is to provide an indication of research patterns associated to particular terms. As a result, we believe that the findings from the examination of the aforementioned primary databases fairly represent general patterns seen by the scientific community about contemporary computer paradigms.

B. First Looked

Initially, we searched for each keyword's earliest occurrence. Since the meanings of some terms may have changed slightly during the past ten years, it was challenging to determine the exact year of first appearance for several keywords. However, Figure 2 shows an approximate timeline. The concept of shifting application logic and data to the edge of the network is how the idea of edge computing originally surfaced in the literature in 2004–2005, as seen in the picture [13], [14]. Then came the Internet of Things and cloud computing. Google and Amazon developed the term "cloud computing" in 2006. In the Search Engine Strategies (SES) event, Eric Schmidt, the CEO of Google, referred to it [15], but Amazon described the Cloud as a commercial product [16]. Scientific articles regarding cloud computing also surfaced later, in 2008 [17], [18]. Regarding the

Internet of Things, the Auto-ID Center at Massachusetts Institute of Technology (MIT) originally introduced the idea in 1999 [19], while the earliest written works come from 2006 [20], [21]. On the other hand, fog computing is clearly rooted. Flavio Bonomi of CISCO made the initial reference and definition of it in 2012 [22].

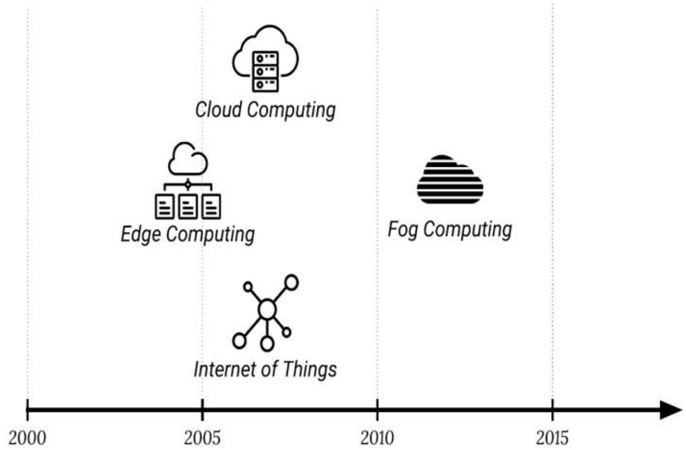

Figure 2. Appearance firstly of Cloud, Edge, Fog computing, and IoT in the literature.

D. Cloud Paradigm (Computing)

Cloud computing is a widely recognized model these days. However, we believe it necessary to summarize the paper's main ideas for the purpose of readability and self-containment.

A. DEFINITION AND ARCHITECTURE

Cloud computing refers to a collective reservoir of adaptable computing resources, including networks, servers, storage, applications, and services. These resources can be rapidly deployed and made accessible with minimal administrative effort or involvement from service providers [1]. It gives a high-level summary of the Cloud and lists the key players along with their functions. Every actor in the context of cloud computing is an entity, meaning that it might be a person or an organization that engages in a transaction or process or carries out specific activities. The cloud provider, cloud consumer, cloud broker, cloud carrier, and cloud auditor are the five primary players. An organization that offers a service to interested parties is known as the cloud provider. An organization that uses services from one or more cloud providers and maintains business ties with them is known as a cloud consumer. The Cloud Broker is an organization that oversees the use, performance, and delivery of Cloud services and settles disputes between Cloud suppliers and Cloud customers. The Cloud Carrier functions as a middleman. An organization that offers a service to interested parties is known as the cloud provider. An organization that uses services from one or more cloud providers and maintains business relationships with them is known as a cloud consumer. The Cloud Broker is an organization that oversees the use, performance, and delivery of Cloud services and settles disputes between Cloud suppliers and

Cloud customers. The Cloud Carrier serves as a middleman between cloud providers and cloud users, facilitating connectivity and the delivery of cloud services. Finally, the Cloud Auditor is an impartial third party that evaluates the Cloud infrastructure, including services, performance, security, and information systems operations.

B. KEY CHARACTERISTICS

The essential characteristics of Cloud computing are summarized below [35]:

1. On-Demand Self-service

When resources are provided on-demand, clients can obtain them as soon as they're needed. When resources are provided automatically through self-service, there is no need for human involvement. When needed, computational power can be delivered automatically, negating the need for direct communication between the service provider and the customer.

1. Broad network access

Many client apps using various types of platforms (such mobile phones and PDAs) can access and provide cloud computing services via the network. Many ways are provided for a wide range of client platforms (Ex. laptops, workstations, and mobile devices) to access computational capabilities over the network.

2. Resource pooling

In order to serve several users, computing resources are combined and dynamically allocated and dealt with based on user demand. Furthermore, the resources provided by the supplier are location agnostic, meaning that the user has no control or knowledge of their precise position.

3. Rapid elasticity

Computer resources can be released and supplied in a flexible manner to scale up or down in response to demand. The consumer believes that processing power is hence limitless and consistently sufficient.

4. Measured service

Based on the nature of the services provided, resource consumption can be tracked and reported. This is especially important for pay-per-use, or charge-per-use, services since it allows for greater transparency between the service provider and the user. The hardware and software that enable the aforementioned fundamental features of cloud computing make up a cloud infrastructure.

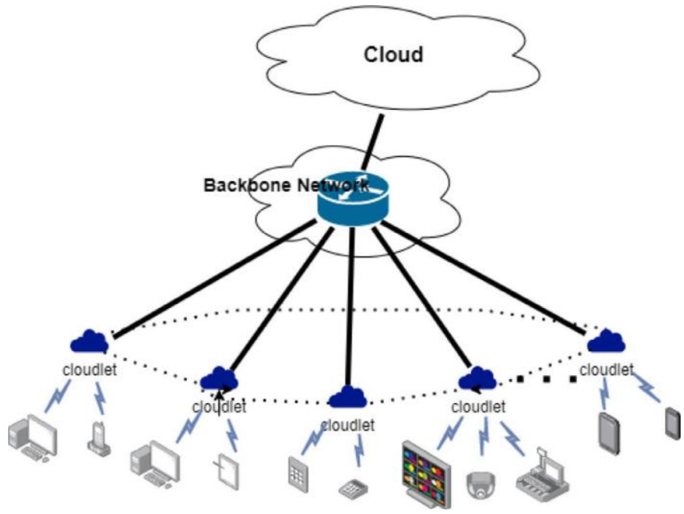

Figure 3. Cloudlet Architecture.

E. Edge Computing

A developed paradigm known as "edge computing" was brought about by the need to relocate compute to the network's edge. Although Edge computing predates the Cloud in literature, its increasing popularity coincides with the emergence of the Internet of Things and its associated new difficulties. This section first explains the basic concept of Edge computing. Next, it defines and explains the three primary Edge computing implementations: Mobile Cloud Computing (MCC), Cloudlet Computing (CC), and Mobile Edge Computing (MEC).

1. DEFINITION

The term "edge computing" refers to the technologies that enable computation to be done at the network's edge, on downstream data for Cloud services and upstream data for Internet of Things services, according to [27]. In basic terms, the goal is to bring cloud computing closer to the network edge so that computation can occur near data sources, or Internet of Things devices. There are several approaches to implement this layer. All the implementations, meanwhile, share many commonalities because they are all created with the Edge paradigm in mind.

2. EDGE COMPUTING IMPLEMENTATIONS

There are several ways to implement the principles of Edge computing, including device types, communication protocols, and services [12], [13]. Below is a description of the main Edge computing implementations:

A. MOBILE CLOUD COMPUTING & CLOUDLET COMPUTING:

Mobile Cloud Computing (MCC) operates on the principle of mobile offloading, where mobile devices transfer storage and computational tasks to remote entities. This approach aims to decrease the workload and optimize factors such as energy consumption, lifespan, and cost. The initial concept of MCC involved transferring data storage and processing from mobile devices to the Cloud, hence expanding the availability of mobile applications to a broader user base beyond those with high performance smartphones [28]. Today, the idea of Mobile Cloud Computing (MCC) has been expanded to incorporate the Edge computing paradigm. The updated concept involves transferring the responsibility of data processing and storage from the Cloud to devices located at the network's edge [26].

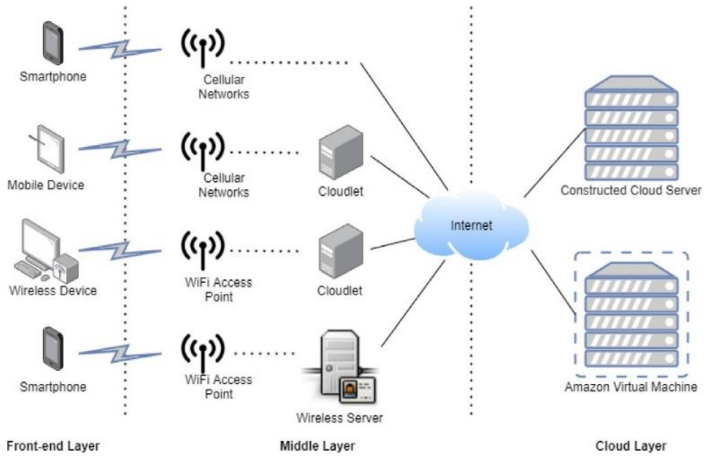

Figure 4. Mobile cloud computing architecture.

B. MOBILE EDGE COMPUTING

Mobile Edge Computing (MEC) is a practical application of the Edge computing concept that enables Cloud computing functionalities (such as computation and storage) to be brought closer to the mobile network's edge, namely within the Radio Access Network (RAN) [26]. Typically, MEC nodes are positioned either alongside the Radio Network Controller or near a big base radio station [13]. Deploying Cloud services within the RAN offers multiple benefits, including location/context awareness, minimal delay, and ample bandwidth [26].

The previously listed implementations of Edge computing possess certain characteristics in common. Both of them share a common objective: to expand the possibilities of Cloud technology to the edge of the network. In addition, they depend on a decentralized infrastructure, which can be accessed over various networks such as wireless, mobile, and Bluetooth, and consists of different devices such as cloudlets and MEC nodes. Furthermore, all Edge implementations offer a range of advantages, primarily derived from their close proximity to the edge of the networks. These include reduced latency, enhanced context and location awareness, increased scalability and availability, and support for mobility.

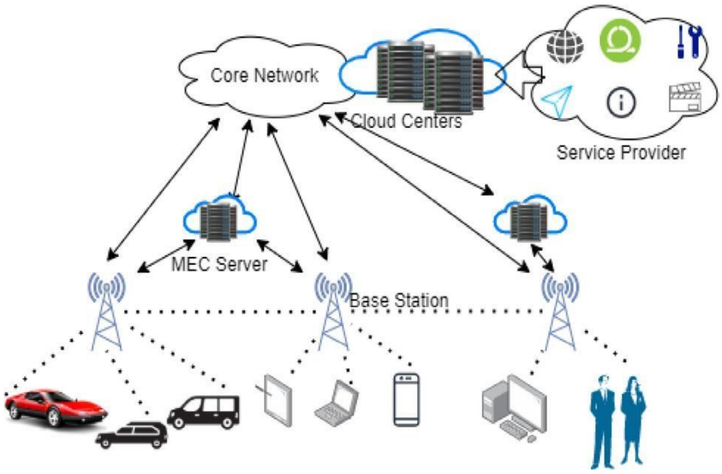

Figure 5. Mobile-edge computing architecture

F. Fog Computing

Fog computing is often seen as an extension of Edge computing [13], [15]. Fog computing offers distributed computing, storage, control, and networking capabilities in close proximity to the user [31].

Even so, in our perspective, Fog computing is not simply another implementation of Edge computing, but rather the most advanced development of the principles underlying Edge computing. Indeed, Fog computing extends beyond the edge of the network and includes the concept of Edge computing. It serves as an organized intermediary layer that effectively connects IoT and Cloud computing. Fog nodes can be placed at any location between end devices and the Cloud, therefore, they are not always directly linked to end devices. In addition, Fog computing not only emphasizes the aspect of "things," but it also offers its services to the Cloud. In this perspective, Fog computing is not only an expansion of the Cloud into the network's periphery, nor a substitute for the Cloud itself. Instead, it is a novel entity that operates between the Cloud and IoT, with the aim of comprehensively facilitating and enhancing their interaction. This involves the integration of IoT, Edge, and Cloud computing. Fog computing is a decentralized technique. It originates from its Edge computing nature and arises from the necessity to surpass the constraints of the centralized approach of Cloud computing. Additionally, Fog nodes have the flexibility to be positioned at any location between end devices and the Cloud infrastructure. The ability to place Fog nodes in various locations is a key characteristic that sets Fog computing apart from other implementations of Edge computing. The definition of Fog computing encompasses the continuum from Cloud to Things. The text discusses the concept of Fog computing, which is an intelligent expansion of Cloud computing designed to connect with IoT devices.

A. ARCHITECTURE

In recent years, there has been significant research interest in defining the architectural paradigm of Fog computing. The majority of research studies on the subject discuss a threetier architecture consisting of Cloud, Fog, and IoT [32],[33]. In addition, the Open Fog Consortium has established a more comprehensive N-layer reference architecture [36], which can be seen as an improvement upon the three-layer architecture. This subsection provides a concise summary of the Fog architecture.

B. THE FOG THREE-LAYER ARCHITECTURE

The fundamental of three-tier structure in Fog computing is illustrated in Figure-6. Fog computing is a significant expansion of cloud paradigm within the Cloud-to-Things continuum. In fact, it serves as the intermediary layer, known as the Fog computing layer, that connects the IoT devices and cloud infrastructure and. The architecture consists of three layers, which are explained below [34].

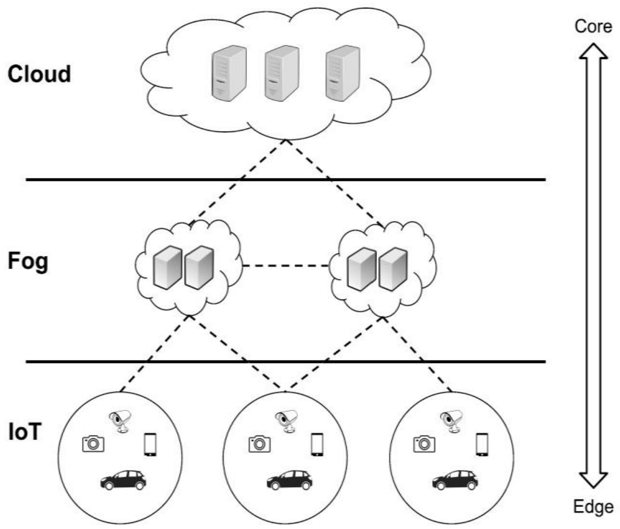

Figure. 6. 3-tier architecture of Fog computing.

1. IoT LAYER

The IoT layer consists of various devices, including sensors, smart vehicles, drones, smartphones, tablets, and more. Typically, they are widely spread across several locations and primarily designed to collect data and transmit it to the higher layer for storage or analysis. However, devices with significant computational capability, such as smartphones, may also carry out local processing prior to engaging higher layers.

2. FOG LAYER

The core of the Fog computing architecture is represented by this layer. The system consists of a substantial quantity of Fog nodes. A Fog node, as defined by the Open Fog Association, is the physical and conceptual network component responsible for executing Fog computing services [36]. Fog nodes possess the capability to do computations, send data, and temporarily store information. They have the flexibility to be positioned at any location between the Cloud and end devices. Consequently, Fog nodes are directly linked to end devices in order to provide services. However, they are linked to the Cloud infrastructure in order to both offer and receive services. For example, Fog nodes can take advantage of Cloud storage and computing capabilities, while also offering users' context information.

3. CLOUD LAYER

This layer mostly consists of the centralized Cloud infrastructure, as explained in Section III. The system consists of several servers that possess advanced processing and storage capabilities, and offers a variety of services. In contrast to the conventional Cloud computing architecture, the Fog architecture allows for the efficient transfer of certain computations or services from the Cloud layer to the Fog layer. This is done to alleviate the burden on Cloud resources and enhance overall efficiency.

C. THE BENEFITS OF FOG COMPUTING

Fog computing acts as an intermediary stratum connecting Cloud computing and IoT. [37], operating in a distributed manner. Therefore, it functions as the cohesive element connecting Cloud computing, Edge computing, and IoT. This is the main advantage of Fog Computing, but it also has the below listed benefits which we will explain them:

1. Security

The Fog computing provides a new viewpoint on security. Within this particular environment, security is regarded as a fundamental element of the architecture, rather than a supplementary and frequently neglected aspect to be added later. The OpenFog Consortium [38] is currently engaged in developing a reference architecture for Fog computing, with a primary focus on security [36]. The Open Fog Security Group (SWG) has established the primary security objectives of Fog computing [39], which we have since reinterpreted and condensed: [39], [37].

- Security as a Pillar (SECaaP): in Fog computing is an inherently secure paradigm that assumes the responsibility of being the responsive, survivable, available, and trusted component in the Cloud-to-Things continuum.

- Security as a Service (SECaaS): in Fog computing is a security service provided to various entities, including both robust Cloud servers and vulnerable IoT devices. The close proximity of Fog nodes to these entities allows the Fog infrastructure to provide essential security services, such as protecting endpoints with limited resources that are often unable to adequately secure themselves, and enhancing existing security solutions, such as strengthening mechanisms for identity verification [46]. This objective should be achieved while ensuring minimal disruption to the operational workflow of the applications/services concerned and adhering to their respective domain architecture.

2. Agility

The process of creating a new service is typically characterized by a slow speed and high costs, primarily attributed to the substantial financial and temporal investments required by major suppliers to introduce or embrace the innovation. The Fog world, on the other hand, provides swift advancement and cost-effective expansion. It serves as an accessible marketplace where people and small teams can use open development tools such as APIs and SDKs, together with the widespread utilization of IoT gadgets, to provide novel services. [22], [39].

3. Cognition

The Fog infrastructure possesses knowledge of customers' wants and goals, enabling it to allocate computing, communication, control, and storage capabilities more precisely across the Cloud-to-Things continuum. This results in the development of applications that more effectively cater to clients' demands. [22], [34], [35].

4. Latency

The Fog architecture facilitates data processing and storage in close proximity to the user, so minimizing latency. Therefore, Fog computing is an ideal solution for achieving real-time processing, particularly for applications that require immediate response [39], [37].

5. Efficiency:

The Fog architecture facilitates the consolidation of processing, communication, control, and storage capabilities at various points along the continuum between the Cloud and IoT. In this concept, the Fog infrastructure utilizes the Cloud to enhance its capabilities and retrieves capabilities from high-powered IoT devices (such as smartphones, tablets, laptops, etc.). These capabilities are integrated into the Fog infrastructure, resulting in improved overall system performance and efficiency. [36], [39], [37].

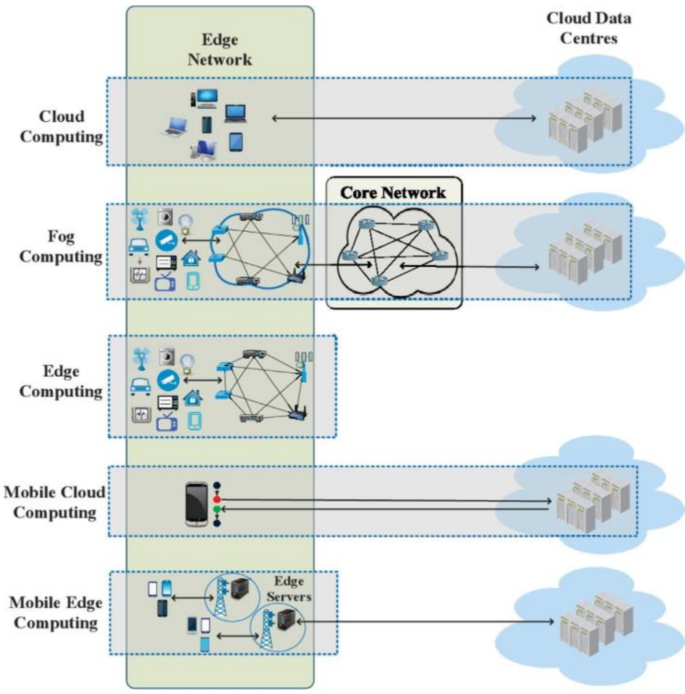

Figure 7. Comprehensive comparison between cloud, edge, fog, mobile edge and mobile cloud computing

G. Major Challenges

We want to provide a concise summary of some significant unresolved issues that, in our viewpoint, should be included in next research endeavors within the subject.

A. Cloud Computing Challenges:

Cloud security is perceived as a significant concern by numerous stakeholders in the field of Cloud computing [40]. The reliability of services supplied by the Cloud has been noted as a significant concern by researchers. If a limited number of data centers are responsible for vital functions, the unavailability of even one data center could have severe consequences. The research endeavors to address this issue by reducing the additional costs associated with catastrophe recovery and enhancing virtual machine migration methods [41].

B. Edge Computing Challenges:

Edge computing, which involves relocating computational processes to the periphery of networks, has several unresolved issues. Recognize the programmability of Edge devices as a challenge. Presently, there exists a significant disparity in the level of adaptability between the programmability of Cloud services and Edge devices, demanding attention and resolution. Furthermore, there is a requirement for naming methods that can effectively manage the extensive number of devices that are expected to be available on the Edge. These schemes should be suitable for extremely dynamic settings. Furthermore, the obstacles that were mentioned pertain to security and privacy, data abstraction, service administration, and optimization issues.

C. Fog Computing Challenges:

Fog computing is now in its early stages of development, resulting in numerous unresolved research issues. Due to its association with Edge computing, Fog computing encounters many similar problems as Edge computing. Thus, it is unsurprising that the capacity to program and handle diverse systems is considered a significant difficulty in the field of Fog computing [42-47]. Furthermore, the authors of this work identify security, interoperability, and energy/resource efficiency as significant obstacles for the use of Fog computing in industrial applications.

H. Discussion and Result:

Table 1. Presents a comparative assessment based on the authors.

Reference	Subjects and Purposes	Message Key	Benefits and Interest

10	Analyzed the challenges associated with fog paradigm and its present state of development. A taxonomy was established by categorizing the mentioned issues according to their core characteristics.	Regarding the advancements in the fog paradigm, it is clear that a significant number of inadequate inputs are still necessary to enhance its capabilities.	Analysis of the distinctions between fog and other paradigms, the difficulties they pose, and the organization of a classification system based on these identified obstacles.
15	Examine the applications of fog computing in relation to real-time systems and expand on their reasons for use and benefits. An examination of the concepts of security and privacy	The susceptibility of the fog computing to network attacks is influenced by its natural environments.	An exploration of the benefits of fog computing across various domains, accompanied by a comprehensive analysis of the associated security concerns.
16	An analysis was conducted on the definition of fog computing and its associated concepts. The text outlines many opportunities and obstacles associated with fog computing.	The incorporation of Software-Defined Networking (SDN) and Network Function Virtualization (NFV) into the fog paradigm will enhance the quality and efficiency of the fog's services.	An exploration into fog computing principles, practical uses, and the difficulties encountered in its design and execution.
21	This study examines and evaluates the architectures of fog computing, along with the associated security and trust issues. In addition, this report emphasizes unresolved matters, emerging research patterns, and prospective subjects.	The scattered and openstructured nature of fog computing renders it susceptible to security concerns.	The contribution encompasses a detailed examination of fog architecture, a concise overview and discourse on open security and trust concerns, and prospects for future research endeavors.

39	The paper provides a concise overview of the fog computing design, key technologies, applications, challenges, and unresolved issues.	The fog computing has enhanced the capabilities of cloud computing. Moreover, the advent of 5G technology would facilitate further advancements and opportunities for growth.	This presentation will include an analysis of the distinctive features of fog architecture, a comprehensive comparison between fog and edge computing as well as cloud computing, an in-depth examination of the essential technologies involved, and a thorough assessment of various challenges and unresolved issues in this field.
44	This study offers a thorough examination of fog-edge computing in order to build a foundation seeking resolutions proposed in studies related to IoTFogCloud environments.	The implementation of artificial intelligence and machine learning will enhance the quality and efficiency of fog computing services.	The essay provided the groundwork for recommended solutions in research pertaining to IoT-Fog-Cloud environments and examined the principles, structures, rules, and tools for IoT-Fog-Cloud.
45	This research conducted a comparison between fog computing and other pertinent ideas. The text provides a taxonomy and organizes works on fog computing and other paradigms, difficulties, and future research goals.	Fog computing is a viable solution for managing the vast quantities of data produced by the Internet of Things.	The paper provided an instructional overview of fog computing and its correlation with other systems. It also included a classification and summary of fog computing challenges and potential future developments.
46	The scholars assess and compare cloud and fog computing by examining the reliable performance and latency of cyberphysical interfaces. They employ Industry 4 to implement real-time embedded machine learning engineering solutions.	The technologies mentioned include cloud servers, fog nodes, machine learning models encoded in PMML, Jmeter, wireless routers, the OpenScoring engine, Raspberry Pi3, Cylon, BMS,PC Driver, and Python.	The findings demonstrated that the fog computing model exhibits greater consistency, reliability, and security compared to the cloud paradigm.

47	The text offers a succinct overview of the obstacles encountered in fog computing and their corresponding resolutions.	The distinctiveness of fog brought about additional issues, separate from those that were already there. In addition, the SDN can be utilized to assist in the management of fog nodes.	An exploration of the diverse privacy and security obstacles encountered with fog computing.
48	The discussion revolved around the principles and concepts of the Fog paradigm, along with related paradigms and technologies.	The Cloud model, which are and Mobile Edge Computing are further technologies that are part of the broader Fog paradigm.	The notable contribution entails furnishing comprehensive foundational knowledge and potentially offering constructive criticism.
49	This study presents a decentralized access control method that employs blockchain and fog computing technology to safeguard IoT data.	The topics of interest are fog computing, blockchain technology, Hybrid and nonlinear chaotic systems in both space and time, as well as the least significant bit.	The trials conducted using the approach demonstrated its ability to successfully safeguard the privacy of IoT data.
50	An analysis was conducted on the current research trends, future architectures, and differences between fog computing and cloud computing. A taxonomy is suggested, along with identified research gaps and legitimate concerns.	A fog node refers to any device that possesses sufficient compute power, network capacity, and storage capacity.	An analysis was conducted on the research trend of fog computing. Analyzed various architectures of fog computing and presented a comprehensive architecture. The text discusses a taxonomy, identifies research gaps, highlights research faults, and addresses open topics.
51	The analysis encompassed 877 conferences and journals pertaining to fog computing and examined the current level of research and challenges in this field.	It is necessary to prioritize the efficiency of fog computing over its robustness.	The essay analyzed the differences between fog computing and cloud computing, explored fogrelated conferences and publications, and assessed the present state of research and its associated difficulties.

52	The paper presented a conceptual framework for implementing an intelligent transport system within the context of fog computing. This framework enables the provision of multiple intelligent systems that can support services and can also be extended to include Internet of Things (IoT) services.	cloud gateways, Fog nodes, and edge devices.	The findings indicate that the suggested CFC-ITS demonstrates resilience in practical ITS implementations.
53	The study proposes the use of Ubiquitous Resource Management for Interference and LatencyAware services (URMILA) as a means of making informed managerial decisions pertaining to dynamic resources. This will help achieve effective trade-offs between fog and edge resources while ensuring that latency requirements for IoT services are met.	Centralized data center refers to a cloud-based infrastructure where data is stored and processed. Microdata center, also known as a fog node, is a smaller-scale data center that is closer to the edge devices. Edge devices are the devices located at the network's edge, such as IoT devices or smartphones.	A novel methodology for resource management throughout the cloud, edge, and fog spectrum has been devised.
54	The IoT-BSFCAN platform is designed to monitor the smart environment in a continuous manner using smart computing devices connected through cloudenabled networks.	cloud gateways, Fog nodes, and edge devices.	The conclusive result suggests that the suggested IoT-BSFCAN system outperforms other available options in terms of efficient performance.
55	A proposal was made for a mobile caching network called CachinMobile, which consists of energy-efficient edge nodes. This network utilizes social networking and device-to-device communications.	Fog servers, Edge node, routers, base station, and cloud servers.	The suggested paradigm is purported to possess markedly enhanced energy efficiency while upholding the quality of service.

56	This work presents a three-layer offloading architecture designed for the intelligent Internet of Vehicles (IoV) with the aim of minimizing overall energy usage while still satisfying users' time restrictions. The problem at hand is broken into two distinct portions: 1) flow redirection and 2) offloading decision. These sections are then addressed and resolved utilizing a system based on deep reinforcement learning.	A network model consisting of three layers, using Fog computing and utilizing a deep reinforcement learningbased method.	The effectiveness of the methods is proven by performance evaluation using real-world data, resulting in a potential energy reduction of approximately 60 percent compared to the default methodology.
57	The study proposes the implementation of fog computing in smart homes to create an ideal healthcare setting for domesticated animals.	Cloud computing, fog computing systems, wireless communication protocol, Secure Sockets Layer (SSL), credential mapping, and Convolutional Neural Network (CNN).	Based on the comparison results, the proposed model demonstrated superior performance compared to other advanced ways in providing veterinary treatment.
58	The study constructed a comprehensive Internet of Things (IoT) system from start to finish. An application that utilizes modern technology and features. Artificial intelligence algorithms and statistical analysis of data Real-time technology for monitoring and managing calves. and identify faulty livestock at an early stage.	Cloud computing and fog computing are both paradigms in the field of information technology. Additionally, Message Queue Telemetry Transport (MQTT) is a communication protocol commonly used in these paradigms.	The results indicate that lameness can be identified three days before to its manifestation. Fog computing enables a decrease in the amount of data that is transmitted to the cloud.

I. Conclusion

This article was created to offer a comprehensive overview of the present state of computing paradigms and their interconnections. This work is the type of material we wished had found when we initially delved into Cloud, Edge and Fog computing. Therefore, we think it a valuable resource for anybody embarking on this subject.

Cloud computing, Edge computing, and Fog computing are the most efficient computing paradigms. Although upon initial review of the literature, understanding the fundamental distinctions and similarities between them, as well as their interrelationships, may prove challenging. Our study offers a clear explanation of these ideas, making it an essential read for researchers beginning their exploration of Edge and Fog computing. initially, we provided an overview of the evolution of several paradigms and the current main areas of research. After that, beginning from this comprehensive overview, we directed our attention towards each of the paradigms, clarifying their primary attributes, structure, and notable attributes, while also providing details about how they interact and relationship to one another. We closed by emphasizing the significance of Fog computing and asserting that Fog serves as the cohesive element that unifies Cloud, and Edge computing. Additionally, a brief overview of current unresolved issues and potential areas of future investigation for Cloud, Fog, and Edge computing was presented to stimulate contemplation.

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